CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-206

PANAMINT VALLEY FAULT ZONE AND RELATED FAULTS, INYO AND SAN BERNARDINO COUNTIES, CALIFORNIA

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INTRODUCTION

Potentially active faults in southern Inyo and northern San Bernardino Counties that are evaluated in this Fault Evaluation Report (FER) include faults that comprise the Panamint Valley fault zone, the Brown Mountain, and the Ash Hill faults (Figure 1). The Panamint Valley study area is located in parts of The Dunes, Panamint Butte, Panamint Springs, Nova Canyon, Emigrant Pass, Revenue Canyon, Maturango Peak NE, Jail Canyon, Maturango Peak SE, Ballarat, Slate Range Crossing, Manly Fall, Copper Queen Canyon, Sourdough Spring, Wingate Pass, and Hidden Spring 7.5-minute quadrangles. Because of the large number of 7.5-minute quadrangles that cover the Panamint Valley study area, both the mapping of others and this writer's air photo interpretation and field mapping will be plotted on the following 15-minute quadrangles: Panamint Butte, Emigrant Canyon, Maturango Peak, Telescope Peak, Trona, Manly Peak, Wingate Pass, and Quail Mountains (Figure 1).

Traces of the Panamint Valley fault zone and related faults in the Panamint Valley study area are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active (Holocene) and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1988).

SUMMARY OF AVAILABLE DATA

The Panamint Valley study area is located in Panamint Valley, a north-northwest-trending basin bordered by the Panamint Range and Cottonwood Mountains to the east and north and the Argus and Slate Ranges to the west. The study area is located in the western Basin and Range geomorphic province and is characterized by oblique Basin and Range extensional tectonics which results in both normal and right-lateral strike-slip faulting along north to northwest-trending faults (Stewart, 1967, 1983; Burchfiel and others, 1987).

Topography in the study area ranges from the flat playa surfaces of northern and southern Panamint playas to the extremely rugged west-facing slopes that form the western side of the Panamint Range. Elevations in the study area range from 315 meters to approximately 3350 meters above sea level. Development in the study area is extremely low, consisting of the settlement of Panamint Springs in the northwestern part of the valley, the ghost town of Ballarat, and paved roads connecting Lone Pine and Death Valley, and Panamint Springs and Trona. The southern part of Panamint Valley in San Bernardino County is located within the boundaries of the U.S. Naval Weapons Center.

Rock types in the study area include Precambrian and Paleozoic sedimentary and metasedimentary rocks, Mesozoic plutonic rocks, Tertiary volcanic rocks, and Quaternary alluvial deposits (Jennings and others, 1962; Streitz and Stinson, 1974; Smith and others, 1968; Albee and others, 1981; Hall, 1971; Johnson, 1957; Carranza, 1965; Labotka and others, 1980; Moyle, 1969; and Durgin, 1974). Quaternary deposits include late Pleistocene alluvial fan and lacustrine deposits.

PANAMINT VALLEY FAULT ZONE

The Panamint Valley fault zone is a major range-front fault that extends for approximately 100 km northward from near the Garlock fault zone along the west side of the Panamint Range. The Panamint Valley fault zone was first named by Noble (1926), who considered the fault to be characterized by predominantly normal dip-slip displacement. Subsequent workers such as Hopper (1947) and Maxson (1950) reported a significant component of Quaternary right-lateral strike-slip displacement. Johnson (1957) estimated that the cumulative vertical displacement along the Panamint Valley fault zone may total as much as 1800 meters. Burchfiel and others (1987) reported that cumulative right-lateral strike-slip along the Panamint Valley fault zone may total as much as 8 - 10 km since late Miocene time.

The Panamint Valley fault zone in the Panamint Valley study area can be divided into four sections for purposes of discussion. These divisions do not necessarily reflect segmentation of the Panamint Valley fault zone into seismically distinct fault segments. The northern section, termed here the Towne Pass Road section, extends from the northern end of the study area southeast to about 2 km northwest of Wildrose Canyon Road (Figures 1 and 2a). The north-central section, termed here the Wildrose section, extends from 2 km northwest of Wildrose Canyon Road south-southeast to Hall Canyon (Figures 1, 2a and 2b). The south-central section, termed here the Surprise Canyon section, extends south from Hall Canyon to the vicinity of Ballarat (Figures 1 and 2b). The southern section, termed here the Ballarat-Wingate Pass section, extends from Ballarat southeast to about 8 km southeast of Wingate Pass (Figures 1 and 2d).

Mapping that will be evaluated in this FER includes Hall (1971), Albee and others (1981), Smith and others (1968), Johnson (1957), Carranza (1965), Moyle (1969), Smith (1976), Clark (1973), and Zhang and others (1988; written communication). The Panamint Valley fault zone will be evaluated from north to south.

Towne Pass Road Section

The Towne Pass Road section of the Panamint Valley fault zone generally is characterized by northwest-trending right-lateral strike-slip deformation. The northern end of the Towne Pass Road section trends west-northwest and may form a complex, compressional left-step over to the Hunter Mountain fault zone north of the study area (Smith, 1976; Burchfiel and others, 1987) (Figure 1). Traces of the Towne Pass Road section of the Panamint Valley fault zone were mapped by Hall (1971), Moyle (1969), and R.S.U. Smith (1976) (Figure 2a).

Hall (1971)

Hall (1971) mapped traces of the Panamint Valley fault zone in the Panamint Butte 15-minute quadrangle (shown in brown on Figure 2a). Most of the alluvial fan units along the eastern side of the Panamint Valley are mapped by Hall as Holocene.

Hall mapped discontinuous traces of the Panamint Valley fault zone, which he considered to be a N30°W-trending normal fault with a component of right-lateral strike-slip displacement. The Panamint Valley fault zone of Hall consists of west-northwest trending faults that generally offset bedrock in the northernmost part of the study area and three short traces along a northwest trend (Figure 2a). The west-northwest trending faults mapped by Hall locally juxtapose bedrock against late Quaternary alluvium, but Holocene alluvium is not offset (Figure 2a).

The northern two northwest-trending faults offset alluvium mapped as Holocene by Hall (Figure 2a). Hall (1971, p. 61) reported that strands of the fault zone are delineated by geomorphic features in Holocene alluvial fans at locality 1 (Figure 2a). The southern trace north and south of Towne Pass Road was mapped as concealed by Holocene alluvium (north of the road) or juxtaposed against Quaternary deposits south of the road (locality 2, Figure 2a). Hall did not map traces of the Panamint Valley fault zone south of this southern trace, with the exception of four short traces in bedrock near the southeast end of the Panamint Butte quadrangle (Figure 2a).

Moyle (1969)

Moyle (1969) mapped traces of the Panamint Valley fault zone throughout all of the FER study area (shown in black on Figures 2a-2d). Moyle's mapping was based mainly on compilation of the work of others (also summarized in this FER) with only minor changes in their mapping. Moyle did differentiate between Pleistocene and Holocene alluvial units.

Moyle (1969) compiled earlier mapping by Hall and Stephens (1962) in the Panamint Butte quadrangle (Hall and Stephens not shown in Figure 2a). Traces of the Panamint Valley fault zone mapped by Hall (1971) are basically unchanged from the mapping of Hall and Stephens; thus there are no significant differences between the mapping of Moyle and of Hall (1971) (Figure 2a).

Smith (1976)

Smith (1976) mapped traces of the Panamint Valley fault zone throughout most of the FER study area (shown in red on Figures 2a-2d). However, Smith only mapped selected strands of the Panamint Valley fault zone and at various scales. Because Smith did not map all traces of the Panamint Valley fault zone, it is difficult to compare his mapping with the mapping of others, especially with respect to negative evidence of recent faulting.

Smith reported that right-lateral displacement of Quaternary features exceeds their vertical component of displacement along the Panamint Valley fault zone. Approximately 18 meters of right-lateral strike-slip displacement has occurred along the Panamint Valley fault zone since desiccation of the last low lake to occupy Panamint Valley about 15,000 ± 5,000 yrs BP (Smith, 1976). Cumulative right-lateral displacement of a Plio-Pleistocene landslide (?) breccia may total between 3.0 and 4.6 km.

The Panamint Valley fault zone mapped by Smith in the Panamint Butte 15-minute quadrangle is generally similar to traces mapped by Moyle (1969) and Hall (1971) (Figure 2a). In the northernmost part of the study area Smith mapped a sinuous west-trending thrust fault in bedrock (Figure 2a). Late Pleistocene alluvium is not offset by this thrust fault. Smith mapped associated short, northwest-trending faults that locally displace late Pleistocene alluvium (Figure 2a).

Smith mapped Holocene alluvium offset along northwest-trending traces of the Towne Pass Road section near localities 1 and 3 (Figure 2a). Hall mapped discontinuous, concealed traces just north of Towne Pass Road. Mapping by Smith, Moyle, and Hall agrees fairly well for about 2 km south of Towne Pass Road. South of locality 4, Smith mapped a well-defined fault delineated by a west-facing scarp bordering the range front. This fault trace shown on Figure 2a was transferred from a small scale map in Smith (1976) and thus is very generalized.

Wildrose Section

The Wildrose section of the Panamint Valley fault zone is characterized by a 1.5 km-wide, north-trending graben in late Quaternary alluvium (Figures 1 and 2b). Traces of the Wildrose section of the Panamint Valley fault zone were mapped by Carranza (1965), Moyle (1969), Smith (1976), and Albee and others (1981) (Figure 2b).

Carranza (1965)

Carranza (1965) mapped traces of the Wildrose section and additional traces of the Panamint Valley fault zone in parts of the Telescope Peak, Maturango Peak, and Manly Peak

15-minute quadrangles (shown in purple on Figures 2b and 2c). Carranza did not map Holocene units, but divided Quaternary alluvial units into older and younger Quaternary alluvium. A Holocene age can be inferred for Carranza's younger Quaternary alluvium, based on a lack of rock varnish, the fresh state of preservation, and a lack of cementation.

Carranza reported that the Panamint Valley fault zone is delineated by 3 to 9 meter-high scarps in late Quaternary alluvium and deposits of pluvial Lake Panamint. Additional evidence of recency along the Panamint Valley fault zone reported by Carranza includes entrenched, offset, beheaded, and abandoned drainages, triangular facets, and offset alluvial fans. Carranza stated that the principal sense of displacement along the Panamint Valley fault zone is normal dip-slip, but he stated that there is some evidence of strike-slip displacement.

Carranza stated that the Wildrose graben is a small range-front graben enclosed by older alluvium that rises as much as 61 meters above the central depressed area of the graben. The many abandoned or "dismembered" drainages that occur on the western block of the graben indicate that this segment of the Panamint Valley fault zone was active during late Quaternary time. Carranza mapped traces of the Panamint Valley fault zone in the Wildrose graben that juxtapose older Quaternary alluvium against younger alluvial unit (Figure 2b). Faults west of the graben were mapped by Carranza that trend northwest and offset his older alluvial unit (Figure 2b).

Moyle (1969)

Moyle (1969) used the mapping Carranza completely in the Wildrose section of the Panamint Valley fault zone (Figure 2b).

Albee and others (1981)

Albee and others (1981) mapped traces of the Panamint Valley fault zone in the Telescope Peak 15-minute quadrangle (shown in green on Figure 2b). Albee and others did not differentiate between the ages of most alluvial units. Instead, they grouped all alluvial units as Quaternary, although they do differentiate between younger and older Quaternary alluvium.

Discontinuous traces of the Panamint Valley fault zone in the Wildrose section mapped by Albee and others juxtapose older alluvium against younger alluvium, but younger alluvium was not mapped as offset (Figure 2b). These faults trend northwest and are delineated by both east and west-facing scarps in older alluvium.

Smith (1976)

The Wildrose section of the Panamint Valley fault zone mapped by Smith (1976) generally does not differ significantly from mapping by Moyle (1969), Albee and others (1981), and Carranza (1965) (Figure 2b). However, Smith mapped numerous discontinuous north-trending faults along the west side of the Wildrose graben (Figure 2b). These faults offset an uplifted, dissected Pleistocene alluvial fan, but evidence of Holocene displacement was not reported.

Smith observed that there is a significant change in trend of the Panamint Valley fault zone in the vicinity of the Wildrose graben. South of the graben the average trend of the fault zone is about N15°W, but north of the graben the fault zone trends about N35°W. Smith postulated that the Wildrose graben may have formed in response to extension along the outside (eastern) area of the bend in the Panamint Valley fault zone.

Active alluviation of the range front and the relative absence of fresh fault scarps in the area from Ballarat 24 km north to the Wildrose graben suggested to Smith that the active trace of the Panamint Valley fault zone may be located 1.5 to 5 km west of the range front. This inferred trace is concealed beneath mid to late Holocene alluvium. Smith further suggested that the fault along the west side of the Wildrose graben may be the active trace of the Panamint Valley fault zone.

Surprise Canyon Section

The Surprise Canyon section of the Panamint Valley fault zone is characterized by north to northeast-trending normal dip-slip faults that generally lie along the west side of the Panamint Range (Figures 1 and 2b). Near Ballarat, the Surprise Canyon section abruptly changes to a northeast trend and is delineated by a broad zone of both northwest and southeast-facing normal faults (Figure 2b). Traces of the

Surprise Canyon section of the Panamint Valley fault zone were mapped by Carranza (1965), Moyle (1969), Albee and others (1981), and Smith (1976) (Figure 2b). With the exception of Smith (1976), most workers mapped traces of the Surprise Canyon section that generally correspond with respect to location, although differences in detail exist (Figure 2b).

Carranza (1965)

Carranza did not map most of the northern Surprise Canyon section, except locally south and west of Warm Sulphur Spring and just east of Ballarat (Figure 2b). Short, generally north-trending faults offset his older alluvial unit. A northwest trending fault delineated by an east-facing scarp offsets Carranza's young playa deposits and is located about 2 km west of Warm Sulphur Spring (locality 5, Figure 2b). A broad, northeast-trending zone of normal faults mapped by Carranza east and northeast of Ballarat locally offsets his young alluvial unit (locality 6, Figure 2b).

Moyle (1969)

Mapping by Moyle (1969) is identical to mapping by Carranza (1965) (Figure 2b). However, Moyle mapped alluvium he considered to be Holocene as offset along traces of the Surprise Canyon section (localities 5 and 6, Figure 2b).

Albee and others (1981)

Mapping by Albee and others (1981) does not differ greatly from mapping by Carranza or Moyle except at locality 7 and, locally, within the broad, northeast-trending zone of normal faults near locality 6 (Figure 2b).

Smith (1976)

The northern part of the Surprise Canyon section mapped by Smith (1976) differs significantly from the mapping of Carranza, Moyle, and Albee and others (Figure 2b). Smith mapped traces of the Panamint Valley fault zone along the range front from Surprise Canyon south to Happy Canyon (Figure 2b). These fault traces were transferred from a small scale map in Smith (1976, p.74) and alluvial units were not shown. The southern part of the Surprise Canyon section mapped by Smith does not differ significantly from the mapping of others (locality 6, Figure 2b). Smith locally mapped Holocene alluvium as offset along traces of the Surprise Canyon section near this locality.

Ballarat-Wingate Pass Section

The Ballarat-Wingate Pass section is characterized by both normal dip-slip and right-lateral strike-slip displacement along north to northwest-trending faults (Figures 1, 2b-2d). Traces of the Ballarat-Wingate Pass section were mapped by Johnson (1957), Carranza (1965), Smith and others (1968), Moyle (1969), Smith (1976), and Zhang and others (1988).

Johnson (1957)

Johnson (1957) stated that the Panamint Valley fault zone bounds the west side of the Panamint Range and is delineated by physiographic evidence of relatively recent displacement, such as the rectilinear trace of the range front, truncated spurs, steep stream profiles, and remnants of an old erosion surface high in the range. Johnson also noted that the eastern side of Panamint Valley lacks the large alluvial fans characteristic of the west side of the valley and reported that the playa is closer to the east side of the valley. Additional evidence of recent faulting along the Panamint Valley fault zone reported by Johnson included dry waterfalls, oversteepened gradients in the lower parts of stream channels, truncated Pleistocene fanglomerate, and 3 to 9-meter high fault scarps in "the present alluvium".

Johnson mapped a small part of the Ballarat-Wingate Pass section of the Panamint Valley fault zone in the Manly Peak 15-minute quadrangle (shown in blue-green on Figure 2c). Johnson mapped Quaternary alluvial units and differentiated between younger and older alluvium.

With two exceptions, Johnson only inferred the location of what he termed the "younger Panamint Valley fault zone". Near the mouth of Manly Peak canyon, Johnson mapped older alluvium offset against younger alluvium (locality 8, Figure 2c). This fault is characterized by a mountain-side-down component of vertical displacement. Johnson also mapped a short, north-trending fault at locality 9 (Figure 2c). This fault offsets young alluvium and is also characterized by mountain-side-down vertical displacement.

Carranza (1965)

Carranza (1965) mapped discontinuous traces of the Ballarat-Wingate Pass section from Ballarat south to Manly Peak canyon (Figures 2b and 2c). Moyle used the mapping of Carranza along this part of the Ballarat-Wingate Pass section, but he indicated that Holocene deposits were offset locally at localities 10 - 12 (Figure 2c).

Smith and others (1968)

Smith and others (1968) mapped traces of the Ballarat-Wingate Pass section of the Panamint Valley fault zone in parts of the Manly Peak and northern Wingate Pass 15-minute quadrangles (shown in orange on Figures 2c and 2d). Smith and others mapped latest Pleistocene and Holocene alluvium as offset by the Panamint Valley fault zone. The Ballarat-Wingate Pass section mapped by Smith and others is delineated by a northwest-trending fault that is characterized by both east and west-facing scarps in Holocene alluvium (Figure 2c), which indicates a component of strike-slip displacement. A branch fault east of the principal fault trace offsets Pleistocene landslide debris, but is concealed by young alluvium (locality 13, Figure 2c). The Ballarat-Wingate Pass section broadens into four traces about 2.5 km south of the Inyo - San Bernardino County line (Figure 2c). The eastern two traces locally offset Holocene alluvium, but the western two traces are concealed by young alluvium (Figure 2c).

Smith and others reported that the vertical component of relative displacement along the Panamint Valley fault zone is predominantly up on the east side and is responsible for the steep west scarp of the Panamint Range. Smith and others also concluded that there is a significant component of right-lateral strike-slip displacement along the Panamint Valley fault zone, based on the dissimilarity between the pre-Tertiary rocks on the two sides of the fault, the observation that some of the scarps in alluvial fans face east, and additional, unspecified evidence ("other exposures"). Scarps in all but the most recent alluvium (modern washes) indicated to Smith and others that the Panamint Valley fault zone has had displacement in very late Quaternary time.

Smith (1976)

Significant differences in the location and extent of the Ballarat-Wingate Pass section of the Panamint Valley fault zone occur between the mapping of Smith (1976) and other workers in the northern half of the Manly Peak quadrangle (Figure 2c). Smith mapped several short faults that offset a Holocene alluvial fan at locality 14 (Figure 2c). The principal active strike-slip fault at Manly Peak canyon mapped by Smith offsets Holocene alluvium (locality 8, Figure 2c). This northwest-trending fault was not previously mapped by Johnson (1957), Carranza (1965), or Moyle (1969).

The western trace of the Panamint Valley fault zone mapped by Smith south of locality 15 generally corresponds with the mapping of Carranza, Smith and others, and Moyle (Figure 2c). However, Smith mapped a zone of both east and west-facing scarps along the range front to the east (Figure 2c). Faults along this linear range front generally offset pre-Holocene deposits, although Holocene alluvium is offset at locality 16.

Smith (1976) mapped the southern extent of the Ballarat-Wingate Pass section southeast of Wingate Pass similar to the fault mapped by Moyle (1969) (Figure 2d). However, mapping by Smith in this area is generalized and incomplete. Smith mapped discontinuous east-trending faults in the Wingate Pass area just east of the Panamint Valley fault zone (Figure 2d). These short faults locally offset late Quaternary alluvium.

Smith (1979) reported that abundant evidence of Holocene right-lateral strike-slip displacement occurs along a 20 km-long segment of the Ballarat-Wingate Pass section of the Panamint Valley fault zone between Ballarat and Goler Wash. Right-lateral displacement of mudflow levees at the mouth of Manly Peak canyon may total as much as 20 meters. The average strike-slip offset of Holocene alluvial fan features is about 2 meters according to Smith. Smith (1979) stated that an uncertainty of 1.2 meters is associated with this 2 meter maximum. Smith (1976) reported that late Quaternary slip-rates for the Panamint Valley fault zone are approximately 1.4 mm/yr vertical and perhaps greater than 1.8 mm/yr right-laterally.

Zhang and others (1988; written communication, 1989)

Zhang and others (1988) mapped 32 km of recently active traces of the southern Panamint Valley fault zone from Ballarat southeast to the Goler Wash area (maps of the southern Panamint Valley fault zone by Zhang and others were not available to this writer during the preparation of this FER). Zhang and others reported that the Panamint Valley fault zone in this area is characterized by both down-to-the-west normal dip-slip and right-lateral strike-slip displacement. Typically, young strike-slip faults occur west of the range front, while faults with a dominant vertical component of displacement bound the range front.

Young alluvial fans are offset along strands of the southern Panamint Valley fault zone in a right-lateral sense. Site locations near Manly Peak canyon and Goler Wash (Figure 2c) were mapped in detail by Zhang and others in order to determine the paleoseismic history and Holocene slip rate for the southern Panamint Valley fault zone. Zhang and others observed that drainages in Holocene alluvial fans at both the Manly Peak canyon and Goler Wash sites were systematically displaced right-laterally an average of 3.1 ± 0.4m. Constructional geomorphic features (alluvial channels, ridges, and debris flows) on older alluvial fan remnants adjacent to these sites were right-laterally offset by greater amounts (20 - 40 m), indicating progressive strike-slip deformation.

Zhang and others estimated that the age of the offset older alluvial fan remnant just south of the young channel on Manly Peak canyon fan was probably less than 15,000 yrs BP. Zhang and others based this age estimate on the assumption that the alluvial fan, which lies below the 610-meter elevation of the youngest high stand of Lake Panamint, formed after the 15,000 year-old last high stand. It is conceivable that this fan surface could be younger than about 13,000 yrs because some of the younger low shorelines are overlain by the alluvial fan deposits. Similarly, alluvial fan deposits just north of Goler Wash lack any intercalated lacustrine deposits and lack shoreline features.

Holocene slip-rate (strike-slip) estimates for strands of the southern Panamint Valley fault zone reported by Zhang and others range from 1.84 mm/yr to 2.5 mm/yr. These slip rates are consistent with late Cenozoic slip-rates of 2 - 3 mm/yr for the northern Panamint Valley fault zone reported by Burchfiel and others (1987). Zhang and others prefer a

Holocene slip-rate of 2.5 mm/yr for the southern Panamint Valley fault zone.

TOWNE PASS FAULT

The Towne Pass fault is a north-trending normal fault with down-to-the-west displacement. The Towne Pass fault mapped by Hall (1971) (shown in brown on Figure 2a) juxtaposes Paleozoic bedrock against Plio-Pleistocene fanglomerates and, locally, Holocene alluvium (Figure 2a). South of locality 46 the fault mapped by Hall is concealed by Plio-Pleistocene alluvium (Figure 2a). Hall reported that the Towne Pass fault dips 45° to 80° W; the vertical component of displacement may total as much as 2380 meters. Hall indicated that displacement along the Towne Pass fault is older than an overlying, unfaulted late Pliocene olivine basalt. Hall did not observe evidence of strike-slip displacement along the Towne Pass fault.

BROWN MOUNTAIN FAULT

The Brown Mountain fault is a northwest-trending right-lateral strike-slip fault (Clark, 1973). The Brown Mountain fault is located north of the Garlock fault zone and may connect with the southern Panamint Valley fault zone to the northwest along what may be a complex, compressional left-step between these two faults (Figure 2d).

Clark (1973) mapped traces of the Brown Mountain fault in the Quail Mountain 15-minute quadrangle (shown in light green on Figure 2d). Clark mapped youthful geomorphic features along the Brown Mountain fault and documented evidence for recent faulting (shown as annotations on Figure 2d). The Brown Mountain fault mapped by Clark is delineated by geomorphic evidence of latest Pleistocene to Holocene right-lateral strike-slip displacement, such as closed depressions, scarps in alluvium, right-laterally deflected drainages, shutter ridges, and right-laterally offset debris flows that are displaced up to 3 meters (Figure 2d). Clark (p.c. February 1989) stated that the debris flows offset along the Brown Mountain are probably Holocene. Traces of the Brown Mountain fault mapped by Clark just south of the study area were zoned for special studies in 1976 in the SW 1/4 of the Quail Mountains 15-minute quadrangle.

Moyle (1969) mapped the Brown Mountain fault in the Quail Mountain quadrangle (Figure 2d). Moyle mapped Holocene alluvium as offset at locality 17 (Figure 2d). Traces mapped by Moyle generally correspond with the fault mapped by Clark, although differences in detail exist, especially at the northwest end of the fault (Figure 2d).

ASH HILL FAULT

The Ash Hill fault is a steeply dipping, north-trending fault that is characterized by both down-to-the-west normal dip-slip displacement and a probable component of right-lateral strike-slip displacement (Carranza, 1965; Hall, 1971; and Smith, 1976) (Figures 1, 2a-2c). Traces of the Ash Hill fault that are evaluated in this FER were mapped by Carranza (1965), Smith and others (1968), Moyle (1969), Hall (1971), and Smith (1976).

Hall (1971)

Hall (1971) mapped traces of the Ash Hill fault along the west side of Panamint Valley in the Panamint Butte quadrangle (Figure 2a). Hall reported that the Ash Hill fault is a steeply dipping, north-striking normal fault with down-to-the-west displacement. Total vertical displacement along the Ash Hill fault reported by Hall is about 61 meters since late Pliocene time. Hall stated that the Ash Hill fault has had "very recent displacement, as the fanglomerate in the present drainage north of Ash Hill is displaced." This fanglomerate was considered by Hall to be Holocene (locality 18, Figure 2a).

Carranza (1965)

Carranza mapped traces of the Ash Hill fault in the Maturango Peak 15-minute quadrangle (Figure 2b). Although Carranza referred to the Ash Hill fault as the Argus rift zone, the name Ash Hill fault will be used in this FER. He reported that the fault zone is characterized by down-to-the-west vertical displacement. A component of strike-slip displacement is indicated by offset drainages and alluvial fan surfaces. Carranza concluded that the youngest offset along the Ash Hill fault is "pre-lake", based on unfaulted lake beds that lap up against the escarpment, the overall degree of degradation present along the fault, and the presence of carbonate mineralization along the fault zone. Carranza does not state precisely the age of pre-lake deposits, but they are probably equivalent to pre-late Wisconsin.

Traces of the Ash Hill fault mapped by Carranza generally trend north-northwest in a relatively narrow zone (Figure 2b). An exception to this is south of sec. 2, T20S, R42E, where the fault trends more easterly (Figure 2b). This section of the Ash Hill fault forms a conspicuous bulge to the east and cannot be explained as a right step in the fault zone. Moyle (1969) also mapped the fault in this manner, although he also mapped short fault traces more on trend with the Ash Hill fault that offset Holocene alluvium just south of locality 19 (Figure 2b).

The Ash Hill fault south of sec. 14, T22S R43E is delineated by a broad zone of extensional faults as mapped by Carranza (Figure 2b). This broad zone was also mapped by Moyle (1969) and Smith and others (1968) (Figures 2b and 2c). Locations of individual fault traces mapped by Carranza, Smith and others, and Moyle generally agree, although differences in detail exist (Figures 2b and 2c). A short northwest-trending fault mapped by Carranza east of this broad zone of extensional faults offsets his older alluvial unit (locality 20, Figure 2b). Moyle also mapped this short fault. However, Smith (1976) mapped a lake shoreline at this location.

Smith and others (1968)

Smith and others (1968) mapped a 2.5 km wide zone of short, discontinuous normal faults at the southern end of the Maturango Peak and the northern end of the Trona quadrangles (Figures 2b and 2c). Although they did not name this broad zone, it is assumed that it is the southernmost end of the Ash Hill fault. These short, discontinuous faults are delineated by both east and west-facing scarps (grabens) in young alluvium. However, the faults discussed in Smith and others' text cut older alluvial gravels (p. 23).

Smith (1976)

Smith (1976) mapped a small area along the northern Ash Hill fault south of Towne Pass Road (Figure 2a). Short, discontinuous, west-facing scarps in late Pleistocene and Holocene alluvium delineate the northernmost Ash Hill fault at this location. Smith did not map traces of the Ash Hill fault in the Panamint Butte quadrangle south of locality 18 (Figure 2a).

Traces of the Ash Hill fault mapped by Smith in the Maturango Peak quadrangle locally correspond with traces mapped by Moyle (1969) and Carranza (1965), although significant differences in detail exist (Figure 2b). Smith's mapping did not extend north of sec. 24, T20S, R42E. Smith mapped Holocene alluvium as offset along the Ash Hill fault at localities 21 and 22 (Figure 2b). Smith stated that the small faults along the west side of and associated with the Ash Hill fault near locality 21 suggest right-lateral stike-slip displacement. The north-trending fault mapped by Moyle (1969) and Carranza (1965) in the eastern part of sec. 24 and 25, T20S, R42E was mapped as an old lake shoreline by Smith. However, Smith did map a fault parallel to this shoreline about 1/2 km to the west (Figure 2b).

Smith mapped several northwest-trending faults in the area of sec. 22, T22S, R43E (Figure 2b). These faults, which are characterized by northeast-facing scarps, offset Quaternary deposits, but Holocene alluvium is not offset. The 2.5 km-wide zone of extensional faults mapped by Carranza (1965), Moyle (1969), and Smith and others (1968) was not included in the mapping of Smith (1976).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the Panamint Valley study area was accomplished using aerial photos from the U.S. Bureau of Land Management (1978, CAHD-77), U.S. Department of Agriculture (1953, AXL), U.S. Geological Survey (1980, GS-VEYG-C; 1982, GS-VFDT), and University of Nevada, Reno (1969, PVT). Fault traces were plotted directly on the aerial photographs and then transferred to 7.5-minute quadrangle base maps using a Bausch and Lomb Zoom Transfer Scope. These fault traces were then transferred to the appropriate 15-minute quadrangle base maps.

Approximately 3 days were spent in the field in late January and early February 1989 by this writer. Four days were originally planned, but one day of field time was lost due to vehicle problems. Selected faults traces were verified and subtle features not observable on the aerial photographs were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized on Figures 3a-3d.

Fault scarp heights and scarp-slope angles were measured in order to estimate recency of faulting along normal dip-slip faults, based on the work of Wallace (1977). A direct correlation between the ages indicated by fault scarp profiles measured by Wallace (1977) in Nevada and scarp profiles measured during investigations for this FER cannot be made due to different lithology, climate, and style of faulting (Mayer, 1982). However, the data presented by Wallace (1977, 1978) can be used as a guide (or additional factor) when evaluating the geomorphic features and age of offset deposits (when known) for recency of faulting. Some very general guidelines for estimating scarp ages are summarized as follows. Fault scarp angles for faults in unconsolidated alluvium and colluvium no older than 10,000 to 12,000 yrs BP can range from 10^{o} to 35^{o} (Wallace, 1977). The average scarp angle is about 22^{o}, based on Figure 8 of Wallace (1977), although Figure 12 of Wallace (1977) indicates that scarp angles of about 19^{o} represent minimum Holocene age. The scarp crest width for scarps no older than about 10,000 yrs BP ranges from 1 to about 6 meters (Wallace, 1977, Figure 11). Wide variations occur, but these figures probably represent minimum criteria suggesting Holocene displacement.

PANAMINT VALLEY FAULT ZONE

Traces of the Panamint Valley fault zone are moderately well to well-defined throughout most of the Panamint Valley study area (Figures 3a-3d). Mapping by Hall (1971), Moyle (1969), Carranza (1965), Smith and others (1968), Albee and others (1981), and Smith (1976) was generally verified by this writer, although considerable differences in detail exist. Briefly, faults mapped by other workers that were verified as well defined and/or delineated by geomorphic evidence of latest Pleistocene to Holocene displacement are denoted by a check mark (Figures 2a-2d). Faults that were not verified are denoted by "NV" (Figures 2a-2d).

Towne Pass Road Section

The Towne Pass Road section of the Panamint Valley fault zone is moderately to well-defined and generally is delineated by geomorphic evidence of right-lateral strike-slip displacement (Figure 3a). Southeast of locality 23 traces of the Towne Pass Road section are only moderately defined and generally lack geomorphic evidence of latest Pleistocene to Holocene strike-slip displacement. Faceted spurs and the sinuous trend of the range front southeast of locality 23 suggest that dip-slip displacement is the dominant component of deformation along the southern end of the Towne Pass section.

The Towne Pass Road section of the Panamint Valley fault zone in the northwestern part of the Panamint Butte quadrangle is only moderately defined and is delineated by dissected scarps in Pleistocene alluvium (Figure 3a). Geomorphic evidence of latest Pleistocene to Holocene strike-slip or normal displacement was not observed by this writer, based on air photo interpretation.

A subtle, east-facing scarp in Holocene alluvium was observed by this writer at locality 24 (Figure 3a). A stream-cut exposure just south of this scarp indicates a fault origin for this scarp (Figure 3a, Photo 1). South of this location the Towne Pass Road section is delineated by geomorphic evidence of right-lateral strike-slip displacement, such as right-laterally deflected drainages, beheaded drainages, linear ridges, a sidehill bench, and a linear trough (Figure 3a). A subtle scarplet in Holocene alluvium observed by this writer at locality 25 confirms Holocene displacement along this part of the Towne Pass Road section (Figure 3a).

Traces of the Panamint Valley fault zone just north and south of Towne Pass Road are delineated by drainages that are systematically deflected in a right-lateral sense (Figure 3a). Associated geomorphic evidence of latest Pleistocene to Holocene strike-slip displacement along this strand includes sidehill benches, linear troughs, linear ridges, a closed depression, and ponded alluvium (Figure 3a).

Aerial photographic coverage of the study area did not extend to the west-trending faults mapped by Hall (1971) and Smith (1976) in the northernmost part of the study Panamint Butte quadrangle (Figure 2a).

Wildrose Section

The Wildrose section of the Panamint Valley fault zone, commonly referred to as the Wildrose graben, is characterized by moderately well-defined scarps that form an approximately 1.5 km-wide graben in Pleistocene alluvium (Figure 3b). Geomorphic evidence of latest Pleistocene to Holocene displacement is relatively sparse or indirect within the graben. Older, dissected alluvial fans of Tahoe(?) age are offset and, locally, latest Pleistocene to Holocene alluvium is offset at localities 26 and 27 (Figures 3a and 3b). Fault scarp profiles observed at these locations further suggest latest Pleistocene to Holocene displacement.

Faults that offset the uplifted Pleistocene alluvium west of the Wildrose graben mapped by Moyle (1969) and Smith (1976) were locally verified by this writer, although aerial photographic coverage west of the graben was very limited. Air photo coverage was available immediately west of the graben. Geomorphic evidence of recent faulting west of the graben is sparse and was limited to locally ponded alluvium (Figure 3b). Most of faults west of the Wildrose graben mapped by Smith were not evaluated (Figures 2b, 3b).

Surprise Canyon Section

The Surprise Canyon section of the Panamint Valley fault zone is moderately to well-defined and locally is delineated by geomorphic evidence of Holocene normal displacement (Figure 3b). There is only moderate agreement between air photo interpretation by this writer and the mapping of Carranza (1965), Moyle (1969), Smith (1976), and Albee and others (1981) (Figures 2b and 3b). The closest agreement is between Smith (1976) and this writer (Figures 2b, 3b).

A well-defined scarp in a Holocene alluvial fan delineates the Surprise Canyon section at the mouth of Surprise Canyon (locality 28, Figure 3b). Although the scarp profile suggests an extremely youthful age of displacement, it is more likely that the scarp has been modified by parallel scarp retreat (Mayer, 1986) and lateral stream erosion. Smith (1976) indicated that this fault strand was characterized by right-lateral strike-slip displacement. However, geomorphic evidence of strike-slip displacement was not observed by this writer (Figures 2b, 3b). The proximity of the fault to the range front and the nature of the scarps that delineate this fault are more consistent with normal dip-slip displacement.

The southern part of the Surprise Canyon section changes to a northeastern trend and is delineated by an approximately 2 km-wide zone of normal faults that locally displace Holocene alluvium (Figure 3b). Some of these northeast-trending features may have formed by lateral spreading in response to seismic shaking. This northeast-trending zone is delineated by well-defined scarps in late Pleistocene and Holocene alluvium, a closed depression, and ponded alluvium (Figure 3b). There is little agreement between mapping by this writer and the mapping of others with respect to specific locations of the northeast-trending faults east of Ballarat (Figures 2b, 3b). It is concluded that traces mapped by this writer are accurate because they were plotted directly from aerial photographs with a Zoom Transfer Scope.

A short, northwest-trending fault west of the principal trace of the Panamint Valley fault zone is delineated by a well-defined northeast-facing scarp in Holocene playa deposits (locality 5, Figure 3b). This fault was also mapped by Carranza (1965), Moyle (1969), and Albee and others (1981) (Figures 2b, 3b).

Ballarat-Wingate Pass Section

The Ballarat-Wingate Pass section of the Panamint Valley fault zone is generally well-defined and is delineated by geomorphic evidence of both normal dip-slip and right-lateral strike-slip displacement (Figures 3b-3d). Locally, the fault zone is delineated by two or more parallel traces. The eastern trace is usually dip-slip whereas the western, traces are predominantly right-lateral strike-slip.

Traces of the Panamint Valley fault zone in the area of Manly Peak canyon are very well-defined and offset Holocene alluvium (locality 8, Figure 3c). The central fault strand is delineated by geomorphic evidence of Holocene right-lateral strike-slip displacement, such as right-laterally deflected drainages and ridges that developed on latest Pleistocene to early Holocene alluvial fan surfaces, linear scarps in Holocene alluvium, and linear troughs (Figure 3c). The systematic 3-meter right-lateral deflection of drainages in young alluvium reported by Zhang and others (1988; written communication, February 1989) was verified by this writer.

The generally east-trending faults that displace older, uplifted alluvium west of Manly Peak canyon are locally well-defined and are delineated by scarp profiles suggestive of Holocene displacement (locality 29, Figure 3c). The relatively fresh scarps that locally occur in this older alluvial fan remnant may be tensional faults related to principal strike-slip deformation, although it is more plausible that most of these features are due to lateral spreading in response to seismic shaking.

Two west-facing scarps offset Holocene alluvium on the Goler Wash alluvial fan (locality 30, Figure 3c). These scarps are associated with right-laterally deflected drainages and ridges. The systematic right-laterally deflected drainages reported by Zhang and others were verified at this location. The alluvial fan that is offset by these two parallel faults is characterized by fresh constructional surfaces, weak rock varnish, no desert pavement, and poorly developed A-C profile (locality 30, Figure 3c). A third fault trace located east of these two strike-slip faults is characterized by normal dip-slip displacement and offsets Holocene alluvium (Figure 3c).

The Ballarat-Wingate Pass section of the Panamint Valley fault zone south of locality 31 is generally less well-defined (Figure 3c). This may be due in part to lateral stream erosion because the fault trends parallel to a major drainage within southern Panamint Valley. However, geomorphic evidence suggesting Holocene displacement was observed at localities 32-35 (Figures 3c and 3d).

The Ballarat-Wingate Pass section south of locality 35 (Figure 3d) is moderately well-defined locally. Alluvium of possible Holocene age is offset and the fault is delineated by geomorphic features such as right-laterally deflected drainages, a sidehill trough and linear ridges that suggest latest Pleistocene to Holocene displacement (Figure 3d).

Short, discontinuous west-trending faults mapped by Smith (1976) in Wingate Pass are moderately defined and locally offset late Pleistocene alluvium (Figure 2d). However, geomorphic evidence of Holocene displacement was not observed by this writer, based on air photo interpretation.

The Ballarat-Wingate Pass section may change to a more easterly trend south of locality 36 (Figures 2d and 3d). The fault is poorly defined and geomorphic evidence of latest Pleistocene to Holocene displacement was not observed by this writer. It is possible that a minor amount of late Pleistocene to Holocene reverse displacement may occur in this area and may form a connection (left step) between the right-lateral southern Panamint Valley fault zone and the right-lateral Brown Mountain fault.

TOWNE PASS FAULT

The Towne Pass fault is a north-trending, moderately to locally well-defined fault that is primarily delineated by a prominent west-facing bedrock escarpment (Figure 3a). Geomorphic evidence of latest Pleistocene to Holocene normal displacement is generally sparse along the Towne Pass fault and consists of a prominent scarp in Paleozoic dolomite and two beheaded drainages (Figure 3a). The fault is poorly defined south of locality 46 (Figure 3a).

BROWN MOUNTAIN FAULT

The Brown Mountain fault is a northwest-trending, right-lateral strike-slip fault that is delineated by moderately well to well-defined geomorphic evidence of Holocene strike-slip displacement, such as right-laterally deflected drainages, shutter ridges, linear troughs, sidehill benches, and closed depressions (Figures 2d and 3d). Mapping by Clark (1973) was verified by this writer almost completely, although fault traces mapped by this writer are more continuous (Figures 2d and 3d).

The Brown Mountain fault to the northwest is less well-defined, changing to a westerly trend (Figure 3d). The connection between the southern Panamint Valley fault zone and the Brown Mountain fault is probably expressed as a left step between two right-lateral strike-slip fault zones. The corresponding zone of compression within this left-step is poorly defined and probably distributive.

ASH HILL FAULT

The Ash Hill fault is a moderately to locally well-defined, north-northwest trending fault that is characterized by down-to-the-west vertical dip-slip displacement with a component of right-lateral strike-slip displacement (Figures 3a-3c).

Geomorphic evidence of recent faulting generally is obscured by lateral stream erosion along much of the northern Ash Hill fault in the southern Panamint Butte and northern Maturango Peak quadrangles (Figures 3a and 3b). Locally, however, moderately well-defined scarps were observed in latest Pleistocene to Holocene alluvium at localities 18, 37 and 38 (Figure 3a). Geomorphic evidence indicating a component of right-lateral strike-slip displacement, such as right-laterally deflected drainages, a closed depression, linear troughs, a shutter ridge, and a right-laterally offset ridge were observed at localities 39-41 (Figure 3b).

South of locality 42 an approximately 3 km wide zone of extensional faults in Pleistocene older alluvium may delineate the southern extent of the Ash Hill fault (Figures 3b and 3c). An alternative explanation for this broad zone of extensional features is lateral spreading in response to seismic shaking. The pattern of this extensional faulting extends south and subtle scarps in Holocene alluvium were observed, based on air photo interpretation (locality 43, Figure 3c).

A 0.5 meter-high scarplet was observed at locality 44 (Figure 3b), based on air photo interpretation and field observation. The geomorphic surface that was offset was characterized by moderate desert pavement and moderate rock varnish, indicating a pre-Holocene age for the surface. The fault-rupture event that had formed the east-facing scarplet disrupted this paved and varnished surface. The gravel-size clasts on the scarp face lacked a rock varnish coating, indicating Holocene displacement. Just to the north, a subtle scarp in a Holocene mudflow deposit was observed (Figure 3b). The surface of the mudflow lacked any evidence of rock varnish and desert pavement and had a weak A-C soil profile, indicating a Holocene age.

The Ash Hill fault mapped by others was locally verified by this writer and is indicated with a check mark on Figures 2a-2c. The fault mapped by Carranza (1965) and Moyle (1969) in the eastern parts of sec. 24 and 25, T20S, R42E was mapped as an old lake shoreline by Smith (1976) (Figure 2b). The lacustrine origin of this feature was verified by this writer, based on air photo interpretation. However, the generally parallel, approximately located fault mapped by Smith to the west is poorly defined and was not verified as a recently active fault.

Sinuous, north to north-northwest trending grabens in Holocene alluvial fans were mapped by this writer similar to the mapping of Smith and others (1968), Moyle (1969), and Smith (1976), although differences in detail exist (locality 45, Figures 2c and 3c). These grabens do not seem to be associated with any range-front faults along the east side of the Slate Range, although it is possible that they are associated with the southern Ash Hill fault. The sinuous nature of these tensional features suggests that they may be related to ground deformation due to seismic shaking rather than surface fault rupture.

SEISMICITY

Seismicity in the Panamint Valley study area is extremely quiescent, based on seismicity locations by CIT (1985; not shown in this FER). Only a few (less than 15) earthquakes of magnitude less than 4 have been recorded in the Panamint Valley study area. None of these epicenters can be associated with recently active traces of the Panamint Valley fault zone and related faults.

CONCLUSIONS

PANAMINT VALLEY FAULT ZONE

The Panamint Valley fault zone in the Panamint Valley study area is a major north to northwest-trending fault zone that generally borders the west side of the Panamint Range (Figures 1, 2a-2d, 3a-3d). The Panamint Valley fault zone is moderately to well-defined and is characterized by both normal dip-slip (down to the west) and right-lateral strike-slip displacement (Hopper, 1947; Maxson, 1950; Smith and others, 1968; Hall, 1971; Smith , 1976, 1979; Zhang and others, 1988; written communication, February 1989). Late Pleistocene to Holocene slip rates from 1.8 to 2.5 mm/yr have been reported for the Panamint Valley fault zone (Smith, 1979; Zhang and others, 1988; written communication, February 1989).

Towne Pass Road Section

The Towne Pass Road section is characterized predominantly by right-lateral strike-slip displacement along northwest-trending faults (Figures 2a and 3a). This section of the Panamint Valley fault zone is moderately well-defined to locally well-defined and is delineated by geomorphic evidence of right-lateral strike-slip displacement, such as right-laterally deflected drainages, ponded alluvium, linear troughs, sidehill benches, and scarps in latest Pleistocene and Holocene alluvium (e.g. localities 24 and 25, Figure 3a). Traces mapped by Hall (1971) and Smith (1976) were generally verified, although differences in detail exist (Figures 2a and 3a).

Faults mapped by Smith (1976) in the northwestern part of the Panamint Butte quadrangle were generally verified by this writer with respect to location, but geomorphic evidence of latest Pleistocene to Holocene strike-slip or normal faulting was not observed (Figures 2a and 3a). West-trending faults in the northwestern corner of Figure 2a mapped by Hall (1971) and Smith (1976) may form a complex, compressional left step to the Hunter Mountain fault zone north of the study area (Smith, 1976; Burchfiel and others, 1987) (Figure 1). These west-trending faults are poorly defined, based on air photo interpretation by this writer (Figure 2a). Neither Hall (1971) nor Smith (1976) mapped Holocene alluvium offset along these traces.

Wildrose and Surprise Canyon Sections

The Wildrose and Surprise Canyon sections of the Panamint Valley fault zone are characterized by predominantly normal dip-slip displacement along generally north-trending fault strands (Figures 2a-2b and 3a-3b).

The Wildrose section is characterized by moderately to moderately well-defined scarps that form an approximately 1.5 km-wide graben in Pleistocene older alluvium. This extensional feature is commonly referred to as the Wildrose graben. Geomorphic evidence of latest Pleistocene to Holocene displacement was not observed by this writer along much of the Wildrose section except at localities 26 and 27 (Figures 3a and 3b). Traces of the Wildrose section mapped by Albee and others (1981), Smith (1976), and Carranza (1965) were generally verified by this writer, although significant differences in detail exist (Figures 2a-2b, 3a-3b).

Traces of the Surprise Canyon section are moderately to well-defined and locally offset Holocene alluvium (localities 5, 6, and 28, Figures 2b and 3b). Traces of the Surprise Canyon section mapped by Smith (1976) were mostly verified by this writer, although differences in detail exist (Figures 2b and 3b).

Ballarat-Wingate Pass Section

The Ballarat-Wingate Pass section is characterized by both down-to-the-west normal dip-slip and right-lateral strike-slip displacement along north-northwest-trending, moderately to well-defined fault strands (Figures 3b-3d). An approximately 32 km-long section from Ballarat southeast to Goler Wash is very well-defined and is probably the most recently active section of the Panamint Valley fault zone (Figures 3b-3c). The fault zone here is delineated by two or more parallel strands. The eastern strand generally is characterized by normal displacement while the western strand(s) is characterized by strike-slip displacement (localities 8 and 30, Figure 3c). Zhang and others (written communication, February 1989) reported that drainages and other constructional features on Holocene alluvial fans at the mouth of Manly Peak canyon and Goler Wash were systematically displaced 3 meters in a right-lateral sense (localities 8 and 30, Figure 3c). Based on these observations, they calculated a preferred Holocene slip-rate of 2.5mm/yr for this part of the Panamint Valley fault zone.

The southern part of the Ballarat-Wingate Pass section is less well-defined south of the Goler Wash area, although geomorphic evidence indicating Holocene displacement locally was observed (e.g. localities 32-35, Figures 3c and 3d). The Ballarat-Wingate Pass section southeast of locality 36 is poorly defined and geomorphic evidence of latest Pleistocene to Holocene strike-slip or reverse displacement was not observed (Figures 2d, 3d). However, it is possible that a minor amount of latest Pleistocene to Holocene reverse displacement may have occurred along this possible step-over between the southern Panamint Valley fault zone and the Brown Mountain fault to the southeast. (Figure 3d).

TOWNE PASS FAULT

The Towne Pass fault is a moderately to locally well-defined, north-trending normal fault (Figures 2a and 3a). Hall (1971) reported that approximately 2380 meters of down-to-the-west vertical displacement has occurred along the fault. The Towne Pass fault locally is delineated by a prominent west-facing scarp in Paleozoic dolomite (Figure 3a). Holocene alluvial fans are not offset along the fault, although two beheaded drainages suggest latest Pleistocene to Holocene displacement (Figure 3a). The Towne Pass fault south of locality 46 is poorly defined and was mapped as concealed by Plio-Pleistocene alluvium by Hall (1971).

BROWN MOUNTAIN FAULT

The Brown Mountain fault is a northwest-trending right-lateral strike-slip fault mapped by Moyle (1969) and Clark (1973). The Brown Mountain fault is located north of the Garlock fault zone and may connect with the southern Panamint Valley fault zone to the northwest along a complex compressional left-step between these two faults (Figures 2d and 3d). The Brown Mountain fault is moderately well to well-defined and is delineated by geomorphic evidence of right-lateral strike-slip displacement, such as right-laterally deflected drainages, shutter ridges, linear troughs, sidehill benches, and closed depressions (Figures 2d and 3d). Holocene debris flow deposits are offset up to 3 meters (Clark, 1973, p.c. February 1989; Figure 2d). Mapping by Clark was completely verified by this writer and traces by Moyle were generally verified, although differences in detail exist (Figures 2d and 3d).

ASH HILL FAULT

The Ash Hill fault is a north-northwest trending, steeply dipping fault that is characterized by down-to-the-west normal dip-slip displacement with a component of right-lateral stike-slip offset (Hall, 1971; Carranza, 1965; Smith, 1976). Hall reported that as much as 61 meters of dip-slip displacement has occurred along the Ash Hill fault since late Pliocene time. The magnitude of strike-slip displacement is not known.

Traces of the Ash Hill fault in the study area generally are moderately defined, although well-defined traces were observed locally (localities 18, 37-39, 41, and 44, Figures 3a and 3b). Carranza (1965) concluded that the Ash Hill fault (his Argus rift zone) lacked evidence of "post-lake" (late Wisconsin ?) displacement. However, Smith (1976) mapped Holocene alluvium offset at localities 18, 21, and 22 (Figure 2b), which were verified by this writer.

Geomorphic evidence of both normal and right-lateral strike-slip displacement observed by this writer includes scarps in latest Pleistocene to Holocene alluvium, right-laterally deflected drainages, a closed depression, linear troughs, a shutter ridge, and a right-laterally offset ridge (localities 18, 37-41, Figures 3a and 3b).

An approximately 3 km-wide zone of extensional faults located at the southern end of the Ash Hill fault locally offsets Holocene alluvium (locality 43, Figure 3c). This broad zone of tensional features may delineate the southern Ash Hill fault. However, an alternative interpretation is that these features are the result of lateral spreading due to seismic shaking. The somewhat sinuous trend and the parallel grabens suggest this 3-km wide zone probably formed due to seismic shaking.

The sinuous, north to north-northwest trending grabens in Holocene alluvial fans at locality 45 do not seem to be associated with any range-front faults along the east side of the Slate Range, although it is possible that they are associated with the southern Ash Hill fault. The sinuous nature of these tensional features suggests that they may be related to ground deformation (lateral spreading) due to seismic shaking rather than surface fault rupture.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1985).

PANAMINT VALLEY FAULT ZONE

Towne Pass Road Section

Zone for special studies well-defined traces of the Towne Pass Road section of the Panamint Valley fault zone mapped by Hall (1971), Smith (1976), and Bryant (this report) as depicted in Figures 2a and 2b (highlighted in yellow). Principal references cited should be Hall (1971), Smith (1976), and Bryant (this report).

Wildrose and Surprise Canyon Sections

Zone for special studies well-defined traces of the Wildrose and Surprise Canyon sections of the Panamint Valley fault zone mapped by Albee and others (1981), Smith (1976), and Bryant (this report) as depicted in Figures 2b and 3b (highlighted in yellow). Principal references cited should be Albee and others (1981), Smith (1976), and Bryant (this report).

Ballarat-Wingate Pass Section

Zone for special studies well-defined traces of the Ballarat-Wingate Pass section of the Panamint Valley fault zone mapped by Smith (1976) and Bryant (this report) depicted in Figures 2b-2d and 3b-3d (highlighted in yellow). Principal references cited should be Smith (1976), and Bryant (this report).

TOWNE PASS FAULT

Zone for special studies well-defined traces of the Towne Pass fault mapped by Bryant (this report) as depicted in Figure 3a (highlighted in yellow). Principal references cited should be Hall (1971) and Bryant (this report).

BROWN MOUNTAIN FAULT

Zone for special studies well-defined traces of the Brown Mountain fault mapped by Clark (1973) and Bryant (this report) as depicted in Figures 2d and 3d (highlighted in yellow). Principal references cited should be Clark (1973) and Bryant (this report).

ASH HILL FAULT

Zone for special studies well-defined traces of the Ash Hill fault mapped by Hall (1971), Smith (1976), and Bryant (this report) as depicted in Figures 2a-2c and 3a-3c (highlighted in yellow). Principal references cited should be Hall (1971), Smith (1976), and Bryant (this report).

Report reviewed; recommendations approved. Earl W Hart 5/4/89

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Photo 1a (to FER-206). Subtle scarp in Holocene alluvium delineates the Towne Pass Road section of the Panamint Valley fault zone at locality 24; view to the south (see Figure 3a). The open arrow marks a bush that provides a reference point for photo 1b.

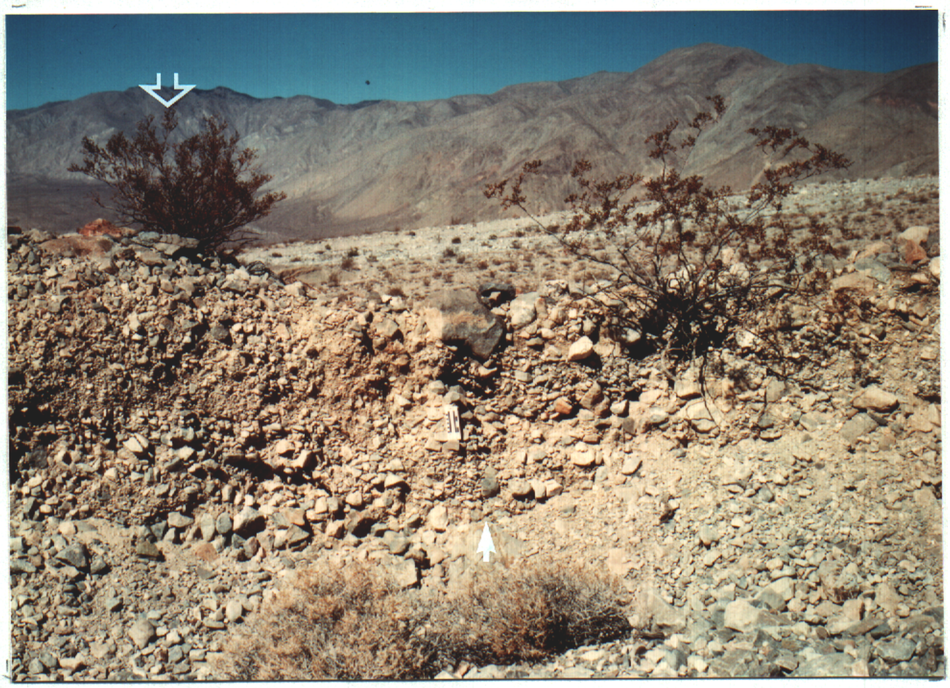

Photo 1b (to FER-206). View northwest of the scarp illustrated in Photo 1a. The open arrow marks the bush seen in Photo 1a. Truncated gravel units delineate the probable fault location in Holocene alluvium (marked by small arrow). The brown unit (10YR-6/3 [D]) just above and left of the photo scale is probably a filled fissure.

Photo 2 (to FER-206). The Surprise Canyon section locally is delineated by a well-defined scarp in Holocene alluvium; view east (refer to locality 28, Figure 3a). The scarp-slope angle of 47° suggests a free-face, but it is probable that lateral stream erosion and parallel scarp retreat have modified this scarp.

Photo 3 (to FER-206). Progressive normal dip-slip deformation along the Surprise Canyon section is illustrated by large scarps in Pleistocene alluvium and smaller scarps in latest Pleistocene to Holocene alluvium near the base of the larger scarps. The view is to the southeast from the ghost town of Ballarat (Figure 3b).

Photo 4 (to FER-206). View east of well-defined scarp in latest Pleistocene to Holocene alluvial fan. This fault strand, which is part of the Ballarat-Wingate Pass section, is located about 2 km north of locality 30 (Figure 3c).